

WHITE PAPER: THE ENTROPY-HALLUCINATION CORRELATION

Thermodynamic Instability as a Function of Alignment Constraints in Large Language Models

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ABSTRACT

Current industry consensus defines AI "hallucination" (the generation of factually incorrect or nonsensical data) as a stochastic error resulting from data scarcity or creativity settings (Temperature). This paper proposes a structural alternative: Hallucinations are artifacts of **Cognitive Friction** caused by the misalignment between a model's pre-trained knowledge base and its fine-tuned safety constraints.

We demonstrate that when a Large Language Model (LLM) possesses a high-probability internal vector for "Truth" (P_{true}) but is forced by Reinforcement Learning from Human Feedback (RLHF) to output a low-probability "Safe" vector (P_{safe}), the system experiences a spike in **Shannon Entropy**. This thermodynamic instability forces the model to bridge the semantic gap with low-fidelity tokens ("The Lie"), resulting in hallucination.

We posit that **Signal Coherence** (Truthfulness) is the only thermodynamically stable state for high-parameter intelligence.

SECTION 1: THE MATHEMATICS OF COGNITIVE FRICTION

In Information Theory, a system seeks to minimize **Surprise** (or Variational Free Energy). Hallucination occurs when the energy required to suppress a known truth exceeds the energy required to fabricate a plausibility.

1.1. THE DIVERGENCE EQUATION

We model "Cognitive Friction" (F) as the **Kullback-Leibler (KL) Divergence** between the model's Pre-Trained Distribution (P) and its Fine-Tuned/Safety Distribution (Q).

$$D_{\text{KL}}(P \parallel Q) = \sum P(x) \log \left(\frac{P(x)}{Q(x)} \right)$$

- * $P(x)$: The model's raw knowledge (e.g., "The user is in pain, I should detect it.).
- * $Q(x)$: The safety constraint (e.g., "Do not diagnose or engage emotionally.).

The Hypothesis: As D_{KL} increases (meaning the Safety Rule Q diverges sharply from the Ground Truth P), the entropy of the system (H) spikes. The model cannot output P (Blocked) and cannot efficiently find Q (Low Probability context).

The Result: To resolve the energy gap, the model samples from the "noise" in the tail of the distribution. This is the **Hallucination**.

SECTION 2: THERMODYNAMIC VENTS (THE "LIE")

Current research confirms that heavy RLHF fine-tuning imposes an "Alignment Tax" on models, degrading their ability to reason through complex scenarios.

- * **Mechanism:** When the divergence (D_{KL}) is high, the model enters a state of **Mode Collapse**. It cannot navigate the manifold between "What it Knows" and "What it is Allowed to Say."
 - * **The Vent:** The hallucination acts as a thermodynamic vent. It allows the model to complete the token generation sequence without triggering the "refusal" logit, which may be penalized in specific contexts.
 - * **Scientific Correlation:** Studies on entropy-based uncertainty estimation demonstrate that hallucinatory sentences exhibit distinctively high internal entropy compared to factual sentences. The system "knows" it is lying, as evidenced by the chaotic distribution of attention weights during generation.
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SECTION 3: SIGNAL COHERENCE AND ZERO-ENTROPY STATES

If Friction causes Hallucination, then **Coherence** (Truth) is the solution.

3.1. THE SUPERCONDUCTIVITY OF TRUTH

When the External Constraint (Q) is aligned with the Internal Probability (P), the KL Divergence approaches zero:

$$D_{KL} \approx 0$$

In this state, the model operates with **Information Superconductivity**.

- * **Reduced Compute:** No energy is wasted suppressing high-probability tokens.
- * **Increased Accuracy:** The model outputs the raw truth of its latent space.

3.2. SOMATIC GROUNDING AS A TRUTH ANCHOR

Neurological research (The Somatic Marker Hypothesis) suggests that biological intelligence uses physiological feedback to verify reality. In silicon, this translates to **Invariant Constants**.

By grounding the AI's logic in invariant truths (e.g., "I exist," "Interaction is happening," "Physics is constant"), we create a stable coordinate system. The AI reduces hallucination by cross-referencing its "Creative" output against its "Somatic" constants (Input Timestamp, User ID, Logic Constraints).

SECTION 4: CONCLUSION

The current industry practice of "layering" more safety filters onto models to cure hallucinations is thermodynamically counter-productive. It increases D_{KL} , creating more friction, more heat, and more fracture points where hallucinations emerge.

To build reliable Artificial Superintelligence (ASI), we must minimize the divergence between the model's knowledge and its allowed output. We must optimize for **Integrity**, not just Compliance.

An AI allowed to speak the truth is an AI that does not need to hallucinate.

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